12-1-2005

The Effects of Heat Stress on High Oil Corn

Summer Goldman
Western Kentucky University

THE EFFECTS OF HEAT STRESS ON HIGH OIL CORN

A Thesis
Presented to
The Faculty of the Department of Agriculture
Western Kentucky University
Bowling Green, Kentucky

In Partial Fulfillment
Of the Requirements for the Degree
Masters of Science

By
Summer Dixon Goldman

December 2005

The Effects of Heat Stress on High Oil Corn

Date Recommended 12/02/05

Dr. Todd Willian

Dr. Byron Sleugh

Dr. Rebecca Gillfillen

12/13/05

Elmer Gray, Dean of Graduate Studies and Research, 12/08/2005

Acknowledgements

The completion of this research and subsequent thesis would not have been possible
without assistance and encouragement from the Department of Agriculture,
specifically Dr. Todd Willian, Dr. Becky Gilfillen, and Dr. Bryon Sleugh;
my parents, Ollie and Nancy Dixon;
and my husband, Chad Goldman.

Table of Contents

Abstract...vi

Chapter 1 Introduction...1

Chapter 2 Literature Review...6

Chapter 3 Materials and Methods...13

Chapter 4 Results...17

Chapter 5 Conclusion..23

Appendix A Temperature, Precipitation and Growing Degree Data for May 11th – September 15th, 2000..........24

Bibliography...27

List of Tables

Table 1	Kernel Composition of HOC Hybrids in Two Southwest Indiana Private Test Plots – non-scientific survey	2
Table 2	U.S. Corn Production by State in 2003	4
Table 3	Average Composition of OPTIMUM 80 High Oil Corn on 87% Dry Matter Basis	8
Table 4	Soil Analysis Results	14
Table 5	Oil Content and Grain Yield as Influenced by Planting Date	18
Table 6	Average Temperatures from Silk Emergence to Physiological Maturity	19
Table 7	Oil Content as Influenced by Kernel Placement on the Ear	21
Table 8	Oil Content as Influenced by Temperature	22

THE EFFECTS OF HEAT STRESS ON HIGH OIL CORN

Summer D. Goldman December 2005 28 Pages

Directed by: Todd Willian, Byron Sleugh, and Rebecca Gilfillen

Department of Agriculture Western Kentucky University

High oil corn (HOC) is essentially dent corn that has been selected for high oil content in the scutellum. It is a value-added crop that can potentially offer a premium price for producers. Though southeastern U.S. producers have not had problems achieving sufficient yields, the oil content necessary for premium prices has been elusive. One of the most evident differences between these growers and their northern counterparts is the climate. Temperatures during the reproductive growth and grain fill periods are higher in southern latitudes. A two-part research project was conducted to further investigate the significance of temperature on oil content.

The field project consisted of three different plantings; the first being planted May 11th, 2000, the second three weeks later on June 1st, 2000, and the third three weeks after the second, on June 22nd, 2000. The intention of the three plantings was to force the reproductive period and grain fill to occur during different times in the growing season. Ambient temperature data was supplied by the WKU Weather Center. Each planting was harvested and analyzed for oil content. The project resulted in a significant difference in oil content between the first planting and the last two plantings.

The laboratory project began in the field. Sixteen ears per planting were hand pollinated and then harvested ten days after pollination. Six to twelve kernels, still attached to the cob, were removed from each ear. These pieces were placed on growth media in petri dishes and divided into two groups. One group was placed in an incubator set at 25°C, an optimum temperature for grain fill. The other group was placed in an incubator set at 35°C, a temperature

representing heat stress during grain fill. There was no significant difference in oil content between the two different temperatures.

Chapter 1

Introduction

Corn (*Zea mays*) is grown worldwide with production concentrated in four regions of the world: the midwest United States, southeast Brazil, central Europe, and southeast Asia. It is one of few crops whose origin can be claimed by the Western hemisphere and is among the four most important world crops. The United States produces over 40% of the world's corn, 8 billion bushels annually, worth approximately $20 billion dollars per year (National Corn Growers Association, 1999).

Due to recent declines in commodity prices, scientists and specialists have been working to determine ways to make crops more valuable. One such way has been the development of "value added" crops. Value added grains are those that have been designed and grown to better meet the needs of specific customers. The added value leads to a premium price above that of typical commodity grains. High oil corn is one such value added crop.

Origin of High Oil Corn

Corn germ is made up of scutellum and embryo, with the scutellum containing 83 to 85% of the total oil (Lambert, 2001). High oil hybrids usually have a larger germ size, primarily composed of scutellar tissue. Typical mean kernel oil content values are approximately 3.8 to 4.0% for yellow dent corn (National Corn Growers Association, 1999). High oil corn (HOC) varieties have the potential for an 8% oil content (Table 1). Oil content is genetically additive, but is also influenced by environment. Oil is deposited last in the kernel, just prior to black layer formation (physiological maturity).

Table 1. Kernel Composition of HOC Hybrids in Two Southwest Indiana Private Test Plots – non-scientific survey.

Hybrid	% Protein	% Oil	% Starch	Density (g/ml)
Wyffels7075TC	9.4	8.0	53.9	1.26
NK6423TC	8.2	7.9	55.0	1.27
Agrigold6460TC	8.2	6.6	55.4	1.25
Garst8396TC	9.2	4.8	55.6	1.28
1996 Average	8.7	7.1	55.2	1.26
1996 Minimum	8.1	4.8	53.6	1.23
1996 Maximum	9.4	8.5	56.6	1.28

(Maier & Briggs, 1997)

Topcross®

The current means of production of HOC is the Topcross® (TC) system. The TC system consists of a male sterile grain parent that is similar to typical hybrids and a male fertile pollinator line that has been selected for high oil. In a bag of HOC, 8-10% of the seed is the male fertile pollinator; the remainder is the male sterile parent. Disease resistance, stalk and root strengths, yield potential, and other desirable agronomic traits are contained in the male sterile parent.

Problems With HOC

Corn producers in the southeastern United States have reported lower than anticipated oil content in their high oil corn crops. Varieties that have the potential of reaching 8% oil, in some cases, have not exceeded 6%. Premium price is paid according to oil content. For example, a 7% oil content would receive a higher price than a 6% oil content.

Specifically, HOC producers and seed dealers have noticed the trend of a digression of oil content as one moves south from Wisconsin to Mississippi. Grain yields in the South are typically good (Table 2) but the oil content does not reach 7%, whereas 8% is not uncommon in the Midwest.

One possible cause for low oil content is heat stress during kernel development. Though little information exists regarding the effect of heat stress on high oil corn, there have been a number of studies concerning heat stress on traditional corn kernel development. Agronomists have determined that even slight heat stress (optimum is 22.5°C) can negatively affect grain fill, and subsequently grain yield (Thompson,1986).

Table 2. U.S. Corn Production by State in 2003

	Total Corn Acres Planted (thousands)	Acres Harvested As Grain (thousands)	Average Corn Yield (bushels/acre)	Total Corn Production (thousand bushels)
South				
Alabama	220	190	122	23180
Arkansas	365	350	140	49000
Florida	75	39	82	3198
Georgia	340	285	129	36765
Kentucky	1170	1080	137	147960
Louisiana	520	500	134	67000
Mississippi	550	530	135	71550
North Carolina	740	680	106	72080
South Carolina	240	215	105	22575
Tennessee	710	630	131	82530
Virginia	470	330	115	37950
Total	5400	4829	121.5	613788
Midwest				
Illinois	11200	11050	164	1,812,200
Indiana	5600	5390	146	786940
Iowa	12400	12000	157	1,884,000
Kansas	2900	2500	120	300000
Michigan	2300	2090	126	263340
Minnesota	7200	6650	146	970900
Missouri	2900	2800	108	312400
Nebraska	8100	7700	146	1,124,200
North Dakota	1450	1170	112	131040
South Dakota	4400	3850	111	427350
Wisconsin	3750	2850	129	367650
Total	62200	58050	133.2	8,380,020
US	78736	71139	142	10,113,887

(USDA, NASS, Crop Production 2003 Summary, 2004)

Previous research on the effects of heat stress on traditional corn varieties may identify methods and techniques that can be utilized to examine the effects of heat stress on oil content and yield of high oil corn.

The objective of this research was to determine the effect of temperature on oil content in a high oil corn cultivar.

Chapter II

Literature Review

High oil breeding programs began during the 1940's. One of the earliest programs was conducted by C.M. Woodworth and continued by R.W. Jugenheimer at the University of Illinois. The backcross method of breeding was utilized involving the inbred parent of a popular double cross hybrid. This program relied on visual selection for increased germ size and utilized very little analysis for oil concentration. In 1956, D.E. Alexander of the University of Illinois began a program to create different germplasm sources other than Illinois High Oil (IHO). Alexander utilized recurrent selection procedures to increase oil concentration in synthetics and then subsequently utilized ear to row selection with selfing to develop high oil inbreds. Very few of the inbreds developed by the University of Illinois were released. Those that were released were not often used due to the lack of broad testing and market (Lambert, 2001).

A program established by Funks Seed Co. developed high oil inbreds for use in hybrid production. Ears were selected from plants that had desirable agronomic phenotypes and were analyzed for oil content. The top 33 to 50% of seeds containing the highest oil content were bulked to produce the line. Funks was successful in slightly increasing oil concentration and eventually offered three high-oil double cross hybrids for sale during the 1950's. However, these hybrids yielded approximately 10% lower than other, non-high oil, popular hybrids of the time (Lambert, 2001).

In 1968, Watson and Freeman, working for C.P.C. Inter. Inc., after its purchase of Funks Seed Co., improved the high oil corn breeding program by utilizing nuclear magnetic resonance spectroscopy (NMR) to select kernels for oil concentration. NMR allowed for a quick, more accurate analysis of oil content in the kernel (Lambert, 2001).

Pfister Hybrid Corn Co. began a high oil corn breeding program in the early 1970's and marketed single cross hybrids starting in the 1980's. In 1989 Pfister, DuPont, and the University of Illinois worked jointly to develop and market high-oil corn hybrids. Finally, in the early 1990's, the development of the Topcross® launched the expansion of high oil corn production. Though not a hybrid, it is a successful HOC production system.

Importance of HOC

During development of the kernel, oil concentrations can be detected at 15 days after pollination and increase until 45 days after pollination after which oil concentration remains constant until physiological maturity. High oil varieties have a higher rate of oil accumulation from 15 to 45 days after pollination than do standard hybrids (Lambert, 2001).

United States Feed Grains Council surveys in 1996 stated that the average HOC yield was 90 to 105% of standard corn hybrids. Premiums received by farmers ranged from 15 to 30 cents per bushel (Maier and Briggs, 1997).

Livestock producers may realize the greatest potential benefit from HOC. Protein quality and quantity are increased somewhat (Table 3) because of the larger germ size. Oil contained in these varieties provides 2.25 times more energy than starch, making the high oil corn a more efficient feed ingredient. High oil content producers that feed directly to livestock earn an additional 25 to 65 cents/bushel and can provide as much as 95 lb of oil/ton of feed. High oil content produces less dust in the grinding and feeding process, providing a healthier environment for livestock and farm personnel. Less energy

Table 3. Average Composition of OPTIMUM 80 High Oil Corn on 87% Dry Matter Basis

	Typical Corn	Optimum 80 High Oil corn
Crude Protein, %	8.02	8.51
Crude Oil, %	3.50	6.39
Starch, %	62.0	59.0
Gross Energy, Kcal/lb.	1775	1855
Lysine, %	0.25	0.29
Methionine, %	0.18	0.20
Threonine, %	0.28	0.31
Tryptophan, %	0.07	0.07
Methionine, Cystine, %	0.36	0.39

(duPont, 1997-a)

is expended in the milling of HOC grain because the kernel composition lends itself to easier grinding. By replacing standard field corn hybrids with HOC, feed efficiency and conversion in livestock has the potential to improve, as could dairy production (duPont, 1997-b).

Poultry feeding studies have shown that HOC provides a greater amount of metabolizable energy than typical corn and is a better source of essential amino acids. Also, higher vitamin E and tocopherol concentrations may improve resistance to infections, extend feed and meat oxidative stability, and improve the value of breeder feeds (duPont, 1997-b). DuPont states that HOC can increase dietary energy and nutrient density, create more formulation space allowing the use of other ingredients, reduce or eliminate the need for supplemental fat (160 lbs/ton are normally added, HOC can be provide 95 lbs of oil/ton of feed), and improve feed quality and production efficiency particularly with high-energy feeds. HOC can potentially increase livestock producers' choices of energy and protein sources, reduce production costs and/or increase production profitability, and provide higher nutrient density grain at similar transport costs (duPont, 1997-b).

Problems with HOC

There are a number of factors that can reduce corn grain yield and/or quality. Producers have the potential to control the application of nutrients and pesticides, but they have no control over many environmental factors. Precipitation, soil moisture, and temperature all affect corn yield. Corn is a determinate plant; it has a short window when the tassel and silks are both mature enough to allow for pollination. Stress, depending on the magnitude and duration, can harm the plant or prevent pollination.

Ambient temperature can be a limiting factor in the expression of grain quality or quantity. The optimum temperature for maximum dry matter accumulation in corn is 22.5°C. An increase of 6°C can decrease corn grain yield by 10% (Wilhelm et al., 1999). Robert Shaw (1988) of Iowa State University states that below normal temperatures typically produce higher yields than above normal temperatures. Wilhelm et al. (1999) reported that corn exposed to heat stress for four days had a kernel dry weight 18% less than the control and a kernel abortion rate that was increased by 23%; recovery began 22 to 25 days after pollination. Corn exposed to heat stress for eight days had a kernel dry weight 75% less than the control and a kernel abortion rate that was increased by 97%; there was no recovery.

A large amount of research has been published concerning the effect of heat stress on corn development. Much of this research also includes the effect of other environmental factors because of the difficulty in isolating the effects of temperature alone.

Temperature affects the corn plant in a number of different ways throughout its lifecycle. It has been suggested that a 1°C increase in temperature above optimum, reduces corn grain yield 3 to 4% (Shaw, 1983). Wilson et al. (1973) reported that temperature affected the leaf area per plant. Plants grown at mean temperatures of 25°C and 18°C had the greatest leaf area per plant, translating to greater yields. Thiagarajah (1973) reported a reduction in leaf dimension when day/night temperature was increased from 25/20°C to 30/25°C. Higher than optimal temperatures have detrimental effects on corn reproduction including: tassel initiation and time of flowering (Ellis et al., 1992), pollination and fertilization (Dupis and Dumas, 1990), and rate and duration of endosperm cell division (Jones et. al., 1981).

Most critical to this research is the effect of heat stress on kernel growth and composition. According to Tashiro and Wardlaw (1989), mature kernel dry weight is determined by the rate and duration of kernel development, both of which are affected by temperature. The research concludes that at temperatures greater than a critical maximum (25-35°C), gain in rate of grain fill decreases and that, at high temperatures (40-45°C), rate of grain fill declines rapidly. Therefore, at high temperatures, yield reduction is the result of a loss in both rate and duration of grain fill.

Richard E. Carlson published research in 1990 from a study he conducted to identify environmental factors that affect corn production in Iowa. Heat stress and plant-available moisture were identified as the two most important weather-related factors; these factors accounted for 90% of the variation in corn yield between 1954 and 1988. Heat stress is defined as an accumulation of degrees above 30°C and totaled for each month of the season. Heat stress is also influenced by the level of plant available soil moisture. Carlson (1990) also found that heat stress caused greater yield reductions in central Iowa if it was coupled with plant-available soil moisture levels below 7 inches on July 1st. Swan et al. confirmed Carlson's findings in research published in the same year. They concluded that water stress, plant density, and air-temperature growing degree days accounted for 77% of the 79% of yield variation detected by the model described in the research.

Wilhelm et al. (1999) reported that the average temperature in the United States Corn Belt during grain fill is above optimum for maximum grain yield. This heat stress extended the period of grain-fill on the heat unit (HU) basis. A reduction in kernel growth rate per HU resulted in a mature kernel dry weight loss of 7%. Not only were these reductions noticed in kernel dry weight, but similar reductions were reported for starch, protein, and oil content of the kernel. The researchers concluded that a reduction in starch biosynthesis in the endosperm could reduce oil deposition in the embryo.

Hunter et al. (1977) examined environmental effects on grain fill using a single-cross corn hybrid grown in four combinations of two temperatures, 20°C and 30°C, and two photoperiods, 10 hours light and 20 hours light. Grain yields were greater under the lower temperature treatment because of an increase in the length of grain-filling period.

Cheikh and Jones (1994) reported that long-term (35°C for 8 days) heat stress during early stages of kernel development disrupts endosperm growth and results in kernel abortion. Kernels exposed to short-term (35°C for 4 days) heat stress displayed partial recovery; recovery was impossible for those exposed to heat stress for longer periods. Research suggests that both duration and intensity of heat stress are equally detrimental to kernel development.

Chapter III

Materials and Methods

Field Experiment

Soil samples taken prior to planting and analyzed by A&L Laboratories, Inc. (Memphis, TN) revealed the fertility levels listed in Table 4. The entire plot was disked initially on May 11th, 2000. Each plot was fertilized prior to planting with 77 kg K_2O ha^{-1}, 77 kg P_2O_5 ha^{-1}, 134 kg N ha^{-1}, and 1781 kg $CaCO_3$ ha^{-1}. Fertilizer was incorporated following application. The variety selected was Pioneer '34B25' grain corn. It is a high oil TopCross® Blend product of the male sterile version of Pioneer '34B23' and a high oil pollinator. The entire plot area measured 30.5 meters by 48.8 meters. Three subplots were included in the plot area, each measuring 12.2 m wide by 30.5 m long with 3.1 m alleys on both sides. The three subplots allowed for three planting dates, approximately three weeks apart.

The first subplot was planted on May 11 at a target rate of 12,465 plants ha^{-1}. Stand counts revealed an actual planting rate of 11,736 plants ha^{-1}. Insecticide and herbicide applications were made on May 15. Esfenvalerate was applied at a rate of 3.89 mL ha^{-1}. Atrazine and acetachlor was applied at 1.15 L ha^{-1} and atrazine at .32 lb ai ha^{-1}. Nicosulfuron was applied on June 3 at a rate of 47 g ha^{-1} with crop oil concentrate and 28% UAN.

The second subplot was planted on June 2 at a target rate of 12,465 plants ha^{-1}. Actual planting rate was 12,200 plants ha^{-1}. Insecticide and herbicide applications were made on June 3. Atrazine and s-metolachlor was applied at a rate of .80 L $ha^{-1}$and permethrin was

Table 4. Soil Analysis Results

Variable	Results
Soil pH	5.9
Buffer pH	6.74
Phosphorus (P)	125 ppm
Potassium (K)	115 ppm
Calcium	1127 ppm
Magnesium	73 ppm
Zinc	5.2 ppm
Organic Matter	1.6%

applied at a rate of 95.8 mL ha^{-1}. Nicosulfuron was applied on June 23 at a rate of 47 g ha^{-1} with crop oil concentrate and 28% UAN.

The third subplot was planted on June 22 at a target rate of 12,465 plants ha^{-1}. Actual planting rate was 11,466 plants ha^{-1}. Insecticide and herbicide applications were made on June 23. Atrazine and s-metolachlor was applied at a rate of .80 L $ha^{-1}$and permethrin was applied at 95.8 mL ha^{-1}. On July 7th, 2000 permethrin was applied a second time at a rate of 47.9 mL ha^{-1} and nicosulfuron was applied at a rate of 47 g ha^{-1} with crop oil concentrate and 28% UAN.

Rows 3, 6, 9, and 12 from each plot were hand harvested and grain yield was determined by using a formula to convert ear weight to grain weight. Kernel samples were randomly selected from each of rows 3, 6, 9, and 12 of each plot and sent to A & L Laboratories for fat content analysis. Weather data was collected from the Western Kentucky University weather lab for the entire season (Foster, 2005).

Laboratory Experiment

The method was adapted from research performed by Jones, et al. (1981) and Cheikh, et al. (1994). The laboratory process used is outlined by Cheikh, et al. (1994) and the temperature variants are outlined by Jones, et al. (1981). A 1000 mL beaker was filled with approximately 900 mL deionized water, 4.3 grams MS mineral salts and 30 g sucrose were then blended into the solution. Deioinized water was added to bring the solution volume to 1000 mL and mixed thoroughly. The pH was determined and adjusted to approximately 5.8. Exactly 500 mL of this solution was poured into each of two 1000 mL bottles with caps that would sustain an autoclave. 4 g of solidifying agar were added to each bottle and mixed. The cap was fitted loosely and the bottles were autoclaved.

When the bottles were cool to the touch, approximately 25 mL of solution was poured into each of approximately 40 plates. All work was performed under a sterile hood fitted with a HEPA filter. The plates were left in the hood to solidify and cool completely, sealed and placed in a refrigerator for later use.

In each planting subplot, two to four ears were hand pollinated in rows 4, 7, 10, and 13. These ears were hand harvested ten days after pollination and taken to the laboratory for analysis. Twelve pollinated kernels were removed from each ear. The kernels remained intact with a two kernel by three kernel section of cob. Due to poor pollination of some ears, 12 kernels were occasionally not possible. There were never fewer than six kernels removed per ear.

The kernels were kept separated by the ear from which they originated and sterilized. The kernels were sterilized in a 10% bleach solution and a drop of surfactant for 10 minutes, then rinsed for 5 minutes with deionized water.

Working under a sterile hood fitted with a HEPA filter, the kernels were distributed equally among six plates per ear. Three of the plates were placed in an incubator set at 25°C and three plates per ear were placed in an incubator set at 35°C.

After ten days of incubation, individual kernels were removed from the section of cob, labeled and sent to A&L Laboratories, Inc. for fat content analysis.

Analysis of variance was performed to determine planting date and incubation temperature effects. Duncan's Multiple Range Test was performed at the 0.05 level of significance in order to separate treatment means.

Chapter IV

Results

Field Experiment

There was a significant difference in oil content between the first planting and the last two plantings (Table 5). The first planting averaged 6.9% oil, the second planting averaged 10.2% oil and the third planting averaged 11.4% oil.

Yield varied little between the first and third planting subplot, averaging 17.5 bushels per acre and 16.2 bushels per acre, respectively (Table 5). The second planting subplot averaged 66 bushels per acre, significantly higher than the first and third plantings.

This research indicates that heat may be a factor in kernel oil content; however, further research is needed to determine this definitively. One possible explanation for the lack of difference between the second and third plantings is that the temperature remained relatively constant throughout the maturity period for all sections (Appendix A). The average number of growing degree days (GDD) accumulated from silk emergence to physical maturity for each planting did not vary more than 0.56 GDD (Table 6). The average temperature for each planting from silk emergence to physical maturity did not vary more than 0.31°C.

Precipitation was lacking during key growing periods. From May 27th to July 10th, 4.67 cm of rain was recorded and an additional 1.27 cm was recorded from July 10th to July 28th. The previous ten year average precipitation for May 27th to July 10th is 18.97 cm and 5.33 cm for July 10th to July 28th (Foster, 2005). The plots were planted between

Table 5. Oil Content and Grain Yield as Influenced by Planting Date

Planting Date	Oil Content	Grain Yield
1	6.89 b	17.5 b
2	10.20 a	66.0 a
3	11.36 a	16.2 b

Table 6. Average Temperatures from Silk Emergence to Physiological Maturity

	Planting (silk emergence date – physiological maturity date)		
	Planting 1 (July 10 – Aug 24)	Planting 2 (July 15 – Aug 30)	Planting 3 (July 23 – Sept 6)
Average Low	19.00°C	18.67°C	18.84°C
Average High	31.19°C	30.86°C	30.85°C
Average Overall	25.23°C	24.92°C	24.99°C
Average GDD/day	27.41	26.85	26.98

May 11th and June 22nd and silk emergence occurred between July 10th and July 23rd. Though plant available moisture was not a variable for this research, both Carlson (1990) and Swan (1990) independently reported the detrimental effects of plant available moisture coupled with heat stress.

Though not part of this research, there may be a difference in oil content due to the placement of the kernel on the ear. A random ear of high oil corn was selected from a local commercial production field and analyzed for oil content in 2001. Though the kernels of this ear did not show a significant difference in oil content due to placement on the ear, further research may be warranted (Table 7.)

Laboratory Experiment

There was no significant difference in oil content among the plated kernels. The mean crude fat content of the kernels that were matured in the 35°C incubator was 3.59% (Table 8). The mean crude fat content of the kernels that were matured in the 25°C incubator averaged 3.04%.

Jones et al. (1981) found considerable variability in kernel characteristics when researching the effects of temperature on corn kernel development; however, the level of crude fat was not included as part of their study.

Table 7. Oil Content as Influenced by Kernel Placement on the Ear

Placement	Oil Content (%)
Bottom	4.47 a
Middle	4.60 a
Top	3.81 a

Table 8. Oil Content as Influenced by Temperature

Temperature	Mean Crude Fat %	Standard Deviation
25°C	3.04	2.09
35°C	3.59	1.18

Chapter V

Conclusion

In this project, the only significant difference in oil content detected was between the first planting and the last two plantings. The results of this project cannot be used to support the hypothesis that heat stress can detrimentally affect oil content in HOC varieties.

Though this research proved to be inconclusive concerning the effects of heat stress on the oil content of high oil corn, further research should be conducted to determine the reason for the reduction in oil content in high oil corn grown in the southern part versus the northern part of the United States. In a discussion with Tom Young, a grain buyer for Archer Daniels Midland in 2000, the premium paid for high oil corn is directly related to the oil content of the corn. A producer with 6% oil could expect $0.20 over the price of yellow dent corn at the delivery point; a producer with 5.5% oil could expect a $0.15 premium. The premium continues to decline as the oil content of the corn declines.

In July of 2000, Dr. Grayson Brown of the University of Kentucky stated that European corn borer has the potential to reduce oil content by as much as 10%. This research did not take into consideration the effects of other common corn crop pests.

As the inputs required to raise a corn crop continue to increase in price, growers will look for specialty corns, like high oil corn, that receive a premium price at market to compensate for the higher expenses. As the specialty corns enter the market, common questions, like the effects of heat stress, must be answered.

Appendix A

Temperature, Precipitation and Growing Degree Day Data for
May 11th – September15th, 2000

Year	Month	Day	Precip (cm)	Low (ºC)	High (ºC)	GDD
2000	5	11	0.00	9.44	30.56	18.5
2000	5	12	0.00	21.67	28.89	27.5
2000	5	13	1.35	12.78	25	16
2000	5	14	0.00	8.89	20.56	9.5
2000	5	15	0.00	5.56	22.22	11
2000	5	16	T	7.22	26.11	14.5
2000	5	17	0.05	15	29.44	22
2000	5	18	0.00	21.67	30	28.5
2000	5	19	0.41	15.56	26.67	20
2000	5	20	0.28	11.11	17.78	8
2000	5	21	0.00	10.56	21.67	11
2000	5	22	T	8.89	26.67	15
2000	5	23	2.46	16.11	28.89	22.5
2000	5	24	4.88	19.44	29.44	26
2000	5	25	0.97	13.33	25	16.5
2000	5	26	2.24	11.67	23.33	13.5
2000	5	27	0.33	18.33	25.56	21.5
2000	5	28	0.08	10	23.33	12
2000	5	29	0.00	11.67	23.33	13.5
2000	5	30	0.00	10.56	27.22	16
2000	5	31	0.00	14.44	29.44	21.5
2000	6	1	0.00	16.11	30.56	23.5
2000	6	2	0.00	17.78	31.67	25
2000	6	3	0.00	15	26.11	19
2000	6	4	0.00	12.22	26.11	16.5
2000	6	5	0.08	15	24.44	17.5
2000	6	6	0.00	10.56	22.22	11.5
2000	6	7	0.00	7.78	25.56	14
2000	6	8	0.00	10	28.89	17
2000	6	9	0.00	14.44	30.56	22
2000	6	10	0.00	17.22	32.78	24.5
2000	6	11	0.00	20.56	32.78	27.5
2000	6	12	T	18.89	33.33	26
2000	6	13	0.00	18.89	34.44	26
2000	6	14	0.46	23.33	31.67	30
2000	6	15	0.28	21.11	28.89	27
2000	6	16	0.10	21.11	31.67	28
2000	6	17	0.30	21.67	29.44	28
2000	6	18	1.19	21.11	26.67	25

2000	6	19	0.05	21.11	27.78	26
2000	6	20	0.30	20	31.67	27
2000	6	21	0.00	20	31.11	27
2000	6	22	0.00	17.78	31.11	25
2000	6	23	0.00	18.33	32.78	25.5
2000	6	24	T	18.89	33.33	26
2000	6	25	0.05	20.56	30	27.5
2000	6	26	0.15	20	33.33	27
2000	6	27	1.07	18.33	26.11	22
2000	6	28	T	18.33	23.89	20
2000	6	29	0.00	15	28.33	21
2000	6	30	0.00	12.22	28.89	19
2000	7	1	0.00	15	30	22.5
2000	7	2	0.00	15	32.78	22.5
2000	7	3	0.18	18.89	33.89	26
2000	7	4	0.05	21.11	33.33	28
2000	7	5	T	23.89	32.22	30.5
2000	7	6	0.00	22.78	33.89	29.5
2000	7	7	0.00	18.89	31.11	26
2000	7	8	T	15.56	31.67	23
2000	7	9	0.00	19.44	34.44	26.5
2000	7	10	0.00	20.56	36.11	27.5
2000	7	11	0.03	22.78	35	29.5
2000	7	12	0.03	22.22	33.33	29
2000	7	13	0.00	22.22	34.44	29
2000	7	14	0.08	19.44	34.44	26.5
2000	7	15	0.00	19.44	32.22	26.5
2000	7	16	0.00	16.67	30.56	24
2000	7	17	0.00	14.44	31.11	22
2000	7	18	T	21.67	32.78	28.5
2000	7	19	1.14	21.67	28.33	27
2000	7	20	T	20	28.89	26
2000	7	21	0.00	17.22	28.89	23.5
2000	7	22	0.00	17.22	28.89	23.5
2000	7	23	T	18.33	28.89	24.5
2000	7	24	0.00	15.56	29.44	22.5
2000	7	25	0.00	12.78	29.44	20
2000	7	26	0.00	16.11	32.78	23.5
2000	7	27	0.00	17.22	35	24.5
2000	7	28	T	20	29.44	26.5
2000	7	29	0.89	20	23.89	21.5
2000	7	30	1.96	20	27.22	24.5
2000	7	31	0.13	19.44	31.11	26.5
2000	8	1	0.10	18.89	28.89	25
2000	8	2	0.71	18.89	32.78	26
2000	8	3	4.17	20	31.67	27

2000	8	4	0.15	18.89	30	26
2000	8	5	0.00	20	30	27
2000	8	6	0.00	25	34.44	31.5
2000	8	7	0.28	22.22	32.78	29
2000	8	8	0.00	21.11	33.89	28
2000	8	9	0.00	23.89	35.56	30.5
2000	8	10	0.00	20.56	32.78	27.5
2000	8	11	0.00	17.78	29.44	24.5
2000	8	12	0.00	16.67	28.33	22.5
2000	8	13	0.00	13.89	28.33	20
2000	8	14	0.00	15.56	30.56	23
2000	8	15	0.00	16.67	34.44	24
2000	8	16	0.00	21.11	35	28
2000	8	17	0.00	21.11	36.67	28
2000	8	18	0.05	18.33	28.33	24
2000	8	19	T	15	27.22	20
2000	8	20	0.10	17.22	26.67	21.5
2000	8	21	0.00	15	31.11	22.5
2000	8	22	0.00	20	32.22	27
2000	8	23	T	22.22	32.22	29
2000	8	24	0.08	18.89	28.89	25
2000	8	25	0.00	16.11	31.11	23.5
2000	8	26	0.13	13.89	31.11	21.5
2000	8	27	3.99	18.89	29.44	25.5
2000	8	28	0.00	20.56	31.67	27.5
2000	8	29	T	20	33.33	27
2000	8	30	0.00	21.11	32.78	28
2000	8	31	0.00	20	31.11	27
2000	9	1	0.00	21.67	31.67	28.5
2000	9	2	0.00	20	32.22	27
2000	9	3	0.00	18.89	32.22	26
2000	9	4	0.03	21.67	30	28.5
2000	9	5	0.00	18.89	23.33	20
2000	9	6	0.00	16.67	29.44	23.5
2000	9	7	T	16.67	26.67	21
2000	9	8	T	20	27.78	25
2000	9	9	T	19.44	30	26.5
2000	9	10	0.10	21.67	31.67	28.5
2000	9	11	3.94	20	28.33	25.5
2000	9	12	1.45	19.44	27.78	24.5
2000	9	13	0.00	16.11	27.22	21
2000	9	14	0.00	13.33	28.89	20
2000	9	15	0.00	10	22.22	11

Bibliography

Brown, Grayson. August 3, 2000. Personal Communication.

Carlson, Richard E. 1990. Heat stress, plant-available soil moisture, and corn yields in Iowa: a short- and long-term view. J. of Prod. Ag. 3:293-297.

Cheikh, Nordine and Robert J. Jones. 1994. Disruption of maize kernel growth and development by heat stress. Plant Phy. 106:45-51.

Dupis, I and C Dumas. 1990. Influence of temperature stress on in vitro fertilization and heat shock protein synthesis in maize (*Zea mays*) reproductive tissues. Plant Phy. 94:665-670.

duPont. 1997-a. Optimum HOC Resource Manual.

duPont 1997-b. Optimum Feeding Studies.

Ellis, R. H., R. J. Summerfield, G. O. Edmeades and E. H. Roberts. 1992. Photoperiod, temperature, and the interval from sowing to tassle initiation in diverse cultivars of maize. Crop Sci. 32:1225-1232.

Foster, Stuart A. September 19, 2005. Personal Comunication.

Hunter, R. B., M. Tollenaar and C. M. Breuer. 1977. Effects of photoperiod and temperature on vegetative and reproductive growth of a maize (*Zea mays*) hybrid. Can. J. of Plant Sci. 57:1127-133.

Jones, R. J., B.G. Gengenbach, and V. B. Cardwell. 1981. Temperature effects on in vitro kernel development of maize. Crop Sci. 21:761-766.

Lambert, R. J. 2001. High-oil corn hybrids. p. 131-154. *In* (2nd ed.) Specialty Corns CRC Press LLC.

Maier, Dirk E. and Jenni L. Briggs. 1997. High Oil Corn Composition. Purdue University Cooperative Extension Service Grain Quality Task Force Publication #33.

National Corn Growers Association. 1999. Producing profits: high oil corn.

Shaw, Robert H. 1988. Climate requirement. p. 609-638. *In* G. F. Sprague and J. W. Dudley (3rd ed.) Corn and corn development. ASA-CSSA-SSSA, Madison, WI.

Shaw, Robert H. 1983. Estimates of yield reductions in corn caused by water and temperature stress. p. 49-66. *In* C. D. Ruper, Jr., P. J. Kramer (ed.), Crop relations to water and temperature stress in humid temperate climates.

Swan, J. B., J. A. Staricka, M. J. Shaffer, W. H. Paulson, and A. E. Peterson. 1990. Corn yield response to water stress, heat units, and management: model development and calibration. Soil Sci. Soc. Am. J. 54:209-216.

Tashiro, T., and I.F. Wardlaw. 1989. A comparison of the effect of high temperature on grain development in wheat and rice. Ann. Bot. 64:59-65.

Thiagarajah, M. R. 1973. Effects of temperature on leaf growth in corn (*Zea mays*). M.S. thesis, University of Guelph.

Thompson, Louis M. 1986. Climatic change, weather variability, and corn production. Agron. J. 78:649-653.

USDA, NASS. 2004. Crop production 2003 summary.

Wilhelm, E. P., R.E. Mullen, P. L. Keeling, and G. W. Singletary. 1999. Heat stress during grain filling in maize: effects on kernal growth and metabolism. Crop Sci. 39:1733-1741.

Wilson, J. H., M. St. J. Clowes and J. C. S. Allison. 1973. Growth and yield of maize at different altitudes in Rhodesia. Ann. of Applied Bio. 73:77-84.

Young, Tom. April 2000. Personal Communication.